REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
March 8, 1993	Reprint

4. TITLE AND SUBTITLE
The Mechanisms of Solar Variability (MSV) Program

5. FUNDING NUMBERS
PE 61102F
PR 2311
TA G3
WU 12

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8. PERFORMING ORGANIZATION REPORT NUMBER
PL-TR-93-2054

9. SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES *National Solar Observatory, **Harvard-Smithsonian Center for Astrophysics - Reprinted from Report of NASA Workshop - NASA Special Publications January 7-9, 1992

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; Distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The Mechanisms of Solar Variability (MSV) Program aims toward understanding the physical causes of variations in the radiative, magnetic, and particle emissions from the Sun. Solar particle and field variations influence the interplanetary medium and the magnetosphere, UV and X-ray variations affect the Earth's upper atmosphere, and total irradiance variations are a possibly significant perturber of tropospheric climate. Solar magnetic variability provides a close-up arena for studying important but otherwise unobservable astrophysical phenomena as well. The MSV program will advance our understanding of the causes of solar variability through high angular resolution observations of the interaction of solar surface magnetic fields and convective motions, as well as related X-ray, ultraviolet, and visible brightness variations. Through these high resolution studies MSV will complement national programs aimed at monitoring integrated solar outputs, thus contributing to the better understanding and ultimate predictability of global solar variability.

14. SUBJECT TERMS
Solar high resolution observations; Solar activity; Observations made from a balloon; X-ray and ultraviolet solar emissions; Solar variability

15. NUMBER OF PAGES
33

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

PL-TR-93-2054

THE MECHANISMS OF SOLAR VARIABILITY (MSV) PROGRAM

Report of a Workshop
Convened by the OSSA
Space Physics Subcommittee,
January 7-9, 1992

The following report is the product of an open, community workshop sponsored by NASA's Office of Space Science and Applications. Although neither the authorship nor the workshop membership is indicated in the body of the report, the topics and content of the report should be attributed to the effort of the entire group. In addition to the two chairmen of the workshop (who are listed as principal authors below), eight peers were selected from the workshop membership to act as session leaders and writers of the individual sections of the final report. These eight persons can be considered as co-authors. The two co-authors listed below are employees of the Phillips Laboratory, Geophysics Directorate.

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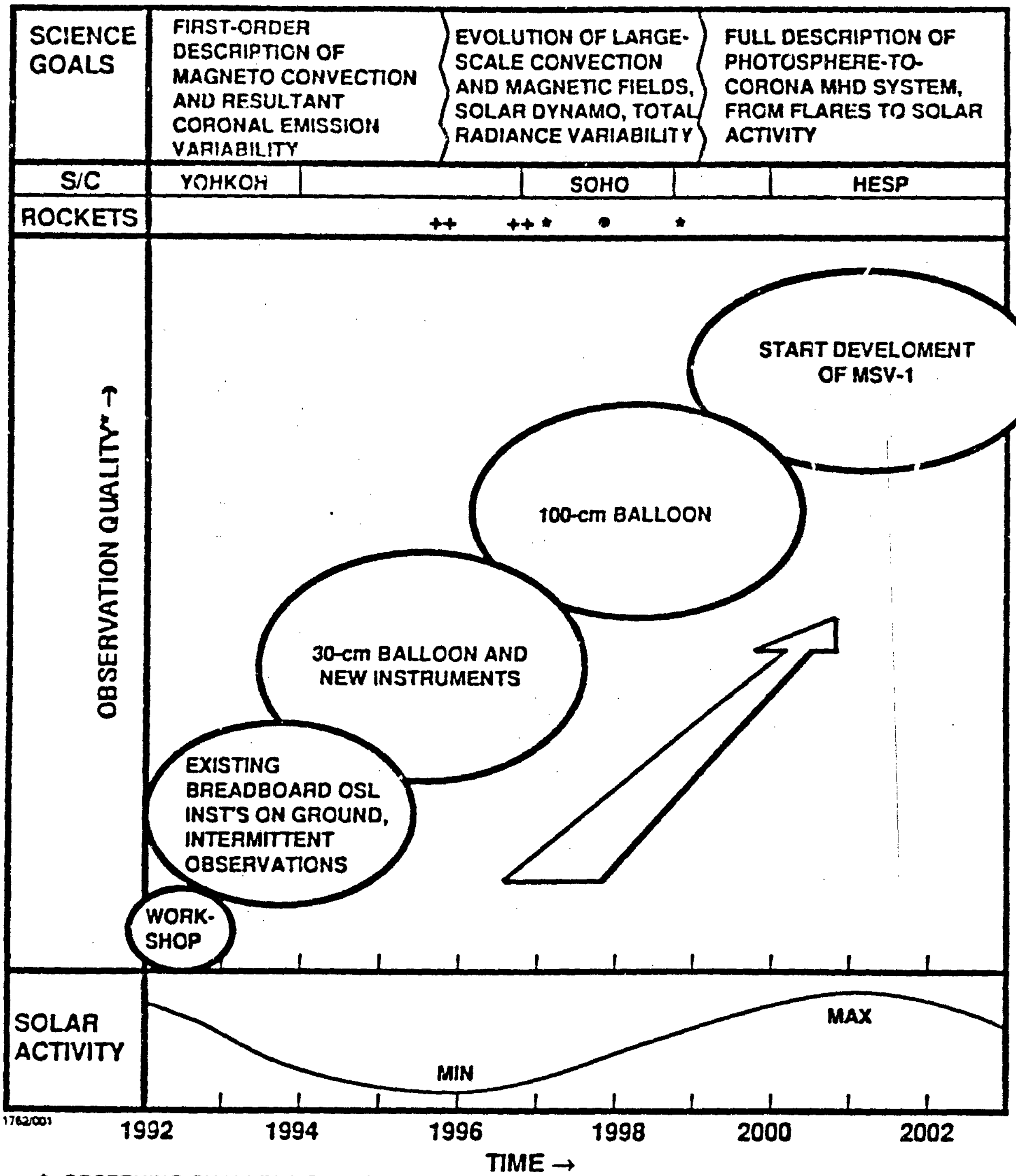
A RESEARCH-BASED ENHANCEMENT TO STUDY MECHANISMS OF SOLAR VARIABILITY (MSV)



* OBSERVING QUALITY INCREASES WITH: ANGULAR RESOLUTION (0.5→0.1 arcsec), OBSERVATION DURATION (MIN→DAYS→CONTINUOUS), COMPLETENESS OF WAVELENGTH COVERAGE, INCLUDING UV, XR DATA

THE MECHANISMS OF SOLAR VARIABILITY (MSV) PROGRAM

ABSTRACT

The Mechanisms of Solar Variability (MSV) Program aims toward understanding the physical causes of variations in the radiative, magnetic, and particle emissions from the Sun. Solar particle and field variations influence the interplanetary medium and the magnetosphere, UV and X-ray variations affect the Earth's upper atmosphere, and total irradiance variations are a possibly significant perturber of tropospheric climate. Solar magnetic variability provides a close-up arena for studying important but otherwise unobservable astrophysical phenomena as well. The MSV program will advance our understanding of the causes of solar variability through high angular resolution observations of the interaction of solar surface magnetic fields and convective motions, as well as related X-ray, ultraviolet, and visible brightness variations. Through these high resolution studies MSV will complement national programs aimed at monitoring integrated solar outputs, thus contributing to the better understanding and ultimate predictability of global solar variability.

The first phase, MSV-0, is a 5-year research base enhancement which builds from existing ground-based optical facilities (limited in resolution by terrestrial atmospheric turbulence) to construction and multiple flights of a 1-m class Solar Balloon-borne Telescope. Coordinated UV and X-ray data will be obtained through an evolutionary series of rocket payloads with arc-second or better angular resolution. Additional data will become available from the Yohkoh, SOHO, and ultimately HESP, satellites.

MSV-0 will build toward a follow-on MSV-1 mission planned to start development in the late 1990s. MSV-1 will combine solar visible-light observations of the required resolution with then state-of-the-art UV and X-ray imaging instruments to permit a thorough "systems approach" to the study of the mechanisms causing magnetic activity variations. While baselined as the currently-defined Orbiting Solar Laboratory (OSL), MSV-1 should be more capable and possibly less expensive, as a result of tradeoffs studied during the MSV-0 program.

EXECUTIVE SUMMARY

MSV is a program to gain better understanding of the Mechanisms of Solar Variability, on timescales ranging from decades (the activity cycle) to milli-seconds (flares). Solar variability (a) produces interplanetary and magnetospheric effects through the variation of particles and fields emitted by the Sun; (b) influences the upper atmosphere of the Earth through UV and X-ray irradiance variations; (c) causes variatio s in total solar irradiance which may influence tropospheric climate; and (d) illuminates a number of important astrophysical phenomena. It is very important to understand what brings about variations in the output from the star at the center of our solar system, which (aside from the Earth itself) is the astronomical object that most matters to human lif

The immediate cause of solar variability is the interaction of magnetic fields with convective motions at and beneath the surface of the Sun. These interaction modulate the total energy flow from the interior, as well as the transport and deposition of energy into the overlying atmosphere, producing variations in UV and X-ray radiation, particle fluxes (the magnetized solar wind), and transient energy release (flares). But the details are unclear, because the relevant spatial scales are of order 100 km (0.1 arc-seconds), so the process cannot be well-resolved by observations from the surface of the Earth (except possibly intermittently and over very small fields of view, using adaptive optics techniques). Also, UV and X-ray small structures need to be studied at the same time as the surface magnetic interactions, and UV and X-ray emission do not penetrate to the surface of the Earth at all.

The solar community has for nearly two decades planned for a space mission, now known as the Orbiting Solar Laboratory (OSL), to obtain high-resolution observations of the solar surface and related phenomena in the upper solar atmosphere. With the postponement of the start of this mission until 1998, the community faces the challenge to maintain the great current scientific momentum of high-resolution solar research, and also the opportunity to improve the scientific return from the advanced solar mission that OSL will become when it finally begins development. Under the aegis of NASA's Solar Management Operations Working Group (Solar MOWG), a workshop was convened to consider this challenge and this opportunity. The community engaged in extensive discussions, first for 5 weeks by electronic mail interchanges, and then in a three-day follow-up meeting (January 7–9, 1992).

The workshop participants recognized that the high-resolution solar physics research that has characterized OSL, and which had originally been advanced primarily because of its astrophysical importance, has additional relevance because of the importance of solar magnetic variability in affecting the heliosphere, geospace, and the terrestrial environment.

Accordingly, we have defined a two-stage program, entitled Mechanisms of Solar Variability (MSV). The first stage, known as MSV-0, will start in FY 1994 and last for five years, thus overlapping by one year the start of the advanced solar mission in FY 1998. It will accomplish the goals of: (a) advancing our current understanding of the physical causes of solar variability, and (b) positioning the science, and the solar research community, to take fullest advantage of the high-resolution solar mission opportunity currently baselined for a new start in 1998 under the label OSL. Here we call this mission MSV-1, to make clear that it will have evolved in its detailed scientific purpose and specific capabilities beyond what OSL is defined to be today.

MSV-0, proposed to be implemented as an OSSA Research Base Enhancement, includes the following components:

- state-of-the-art ground based observational research at approximately arc-second resolution using prototype OSL instruments, aided by emerging adaptive optics techniques to obtain limited data at scales approaching 0.1 arc-seconds.
- development and use of a 0.1 arc-second resolution, 1-m class Solar Balloon-borne Telescope (SBT), with precursor flights of a 0.3-m telescope.
- an evolutionary program of rocket flights for UV and X-ray data, with increasing angular resolution; these to be coordinated with the first two components above.
- a focussed theory program aimed at defining key observations needed, and interpreting the data from, the above observational components.

MSV-0 will make a very significant contribution toward our scientific understanding of the mechanism of solar variability. It will obtain the first observations with enough spatial resolution, field of view, photometric accuracy, and coordinated visible and UV/X-ray data, to:

- Show how the chromosphere and corona are magnetically linked to, and driven by, the photosphere on the scale of individual magnetic flux tubes. (Needed to test any model of coronal heating.)
- Tightly constrain models of individual photospheric flux tubes. (Needed for a quantitative physical understanding of the Sun's luminosity variation.)
- Test the belief that flares are releases of an active region's stored magnetic energy. (Result will be a new fundamental constraint on flare models.)
- Reveal whether active regions disappear mostly from submergence of their magnetic flux. (Important new information for dynamo theory.)

In addition to the direct scientific return from MSV-0, it will maintain the scientific and technological momentum already developed under the OSL program, and should lead toward the end of the decade to the start of an MSV-1 mission with even greater scientific capability, and perhaps less cost, then that projected for OSL.

The MSV-0 program will be open to all qualified investigators, selected in response to a single NASA Research Announcement. Periodic scientific workshops will ensure that the different program elements are well-coordinated and well focussed toward the specific scientific goals of MSV-0. The program will be coordinated by a NASA Project Office, with the active participation of an Investigators Working Group.

The projected cost for the MSV-0 program is $37.6 M (1992 dollars), distributed as follows:

Year	*Funding ($M, 1992)*
1994	7.37
1995	7.91
1996	7.87
1997	7.92
1998	6.53
1994–8	37.60

THE MECHANISMS OF SOLAR VARIABILITY (MSV) PROGRAM

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THE MECHANISMS OF SOLAR VARIABILITY (MSV) PROGRAM

I. SCIENTIFIC RATIONALE

The Sun is a magnetic variable star. Solar magnetic processes produce changes in the Sun's emission of UV, X-rays, and penetrating ionizing particles, and even its total luminosity ("solar constant"). This variability produces effects at all altitudes in the Earth's atmosphere. After years of uncertainty and controversy, it is now known that the luminosity of the Sun varies over the years, in step with the level of magnetic activity, raising the possibility that solar forcing may affect the Earth's climate. This possibility is suggested both by decade- and century-long tracking of mean annual temperature with solar activity, and by studies of the luminosity and activity variations of other solar-type stars. The climatic effects are expected to be most prominent when the Sun unaccountably slips into prolonged periods of very low or very high activity, as in the 15th and 17th centuries and the 12th century, respectively. There is increased urgency in exploring the physics of solar variability today because of its possibly profound practical implications.

Mass loss from the Sun, i.e. the solar wind, produces the heliosphere and the variety of interplanetary and planetary plasma activity within it. But the energy source for the solar wind, i.e. coronal agitation and heating, is still a matter of conjecture. It is essential for a complete scientific picture of the heliosphere, solar mass loss, and stellar winds and mass loss in general to resolve this basic question. This requires detailed high resolution studies of convective and magnetic activity in the solar photosphere, together with studies of the resultant effects in the overlying corona.

The Sun is also a laboratory for pursuing the complex physics of astrophysical magnetic activity in general. Solar data show that stellar magnetic activity is dynamic in nature, and involves physical effects not previously imagined. The magnetic activity of other stars presumably arises in much the same way as solar activity, so that we can hope to understand the activity of stars only after we understand the activity of the magnetic fields on the Sun. Because similar magnetic phenomena occur in many other astrophysical objects, understanding solar activity is important to the whole field of astronomy. As an example, X-ray astronomy is limited largely to phenomenology until the cause of the X-ray emission is understood, and that is certainly not possible in detail until the cause of the solar X-ray corona is understood.

The essential point is that the magnetic activity of the Sun reveals universal astrophysical phenomena. Its origins in the Sun lie in the dynamics of current sheets and magnetic fibrils with characteristic scales well below 200 km (0.3") and temperatures from 4×10^3 K to 10^7 K. The physics of the activity is complex and extends beyond conventional notions and ideas, so that scientific progress depends upon observational guidance into the unknown. It is clear that surface magnetic fields and their stresses in some way produce changes in radiation from both the hot overlying atmosphere and the deeper solar interior. However, ground-based telescopes provide neither the necessary spatial resolution nor the required wavelength coverage for detailed studies of this cause-and-effect behavior. So the crucial observations can be accomplished ultimately only with high resolution observations from space. This scientific situation is a central driver of current planning in solar physics.

A specific example of the need to observe the solar photosphere and atmosphere together as a system is provided by solar flares. There have been numerous attempts to observe the high energy characteristics of flares simultaneously in many wavelength bands, in order to understand the energy transport mechanisms that produce the different aspects of flares. But there are no simultaneous high energy and photospheric observations, both with high resolution.

It is also necessary to obtain observations with high spectral, as well as high spatial resolution. In the visible this allows isolation of different height regimes (e.g. the Ca II H and K lines) and measurement of magnetic and velocity fields. At XUV wavelengths this allows measuring velocities, densities (through line ratios), and radiated energy rates at various heights.

Further insights into the physical causes of the magnetic activity variations that influence the solar system, as well as a major part of astronomical science, are hindered by lack of extensive observations of the Sun at high resolution and broad wavelength coverage. The MSV program is aimed toward the goal of providing such observations, and using them to provide the needed insights. At present, there are no simultaneous arc-second resolution observations that cover the same solar atmospheric area from the photosphere to the corona, so even a small sample of data, such as provided by the MSV-0 program, would constitute a major advance.

MSV-0 will incorporate a coordinated program of visible observations from ground and balloon platforms, together with occasional UV and X-ray observations from rockets; this should provide the first well-coordinated attack on determining the fine scale structure of the Sun's atmosphere seen as a system from photosphere to corona. MSV-0 will also lay the groundwork for development, toward the end of the decade, of MSV-1, an advanced solar space mission dedicated to studying the physical causes of solar variability at high angular resolution in visible, UV, and X-ray wavelengths.

MSV-0 is not a stand-alone program. To understand solar variability from a solar-terrestrial perspective there is need for measurement of global output variations, on timescales from decades (the solar cycle) to milliseconds (flares). Other programs (e.g. SOURCE, RISE, UARS, SOLSTICE, SUSIM, SOHO, etc.) are under definition or development or already in operation. The MSV-0 program will tie in to these efforts because the study of the detailed mechanisms that underlie localized magnetic variations will then allow extrapolation to variability on the global scale. A good example is provided by studies of the energy budget of magnetic active regions and the magnetic "network" far from active regions, to infer the spatially integrated outputs of the Sun as a whole. It would be very productive if MSV-0 observations were able to overlap global solar monitoring programs such as those named above.

By focussing quite specifically on the detailed *mechanisms* of solar variability, MSV-0 will enhance programs monitoring global solar variability. Through coordination with data from these programs, MSV-0 should lead to better understanding of just how the observed variability is produced, and perhaps help in predicting the range and timing of future variability. To this end, it is important for the success of MSV-0 that monitoring programs such as those mentioned above be carried out during the MSV-0 timeframe.

2. THE MSV-0 PROGRAM

2.1 *THE GROUND-BASED COMPONENT OF MSV-0*

2.1.1 Introduction

The ground-based component of MSV-0 will maintain progress in understanding the three-dimensional structure of the solar atmosphere by obtaining and analyzing new state-of-the-art high-resolution observations, refining existing instrumentation and observational techniques, and developing new types of instrumentation. The OSL instrument development and observing programs have already contributed to the clarification of essential physical questions. Modern techniques using adaptive optics, high-speed guiders, image selection and re-registration, and image processing have produced significant advances in observations from the ground. MSV-0 will extend these successes. Ground-based observations will be particularly valuable to MSV-0 because:

a) They serve to define and refine the science observing programs, the operational characteristics of instruments, and quick look, calibration, and data handling systems. They can begin immediately, thus preserving existing scientific momentum. Together with a strong data analysis program, they will provide critical inputs to theory and modeling of fine-scale solar structures.

b) Existing telescopes, located at sites with excellent seeing, and including state-of-the-art instrumentation, offer an opportunity for approaching the sub-arc-second spatial resolution barrier that separates the best ground-based from potential space-borne observational capabilities. These facilities will allow the refinement of existing instrumentation and the development and testing of new ones that may be applicable to future space missions.

c) By complementing data from the balloon and rocket components of MSV-0, and from the Yohkoh and SOHO satellites, ground-based programs will provide important preliminary glimpses of the three-dimensional structure of the outer solar atmosphere.

2.1.2 Current Status of High Resolution Ground-Based Solar Research

There has been remarkable progress in high-resolution ground-based research in the past few years, in part under the stimulus of the OSL program. Engineering and evaluation units for the OSL visible light instruments have been deployed at ground-based observatories both to characterize and improve their performance characteristics and to help refine the scientific goals and observing programs that would be later carried out from a large space observatory. Scientific progress was accelerated because the results from a shuttle Spacelab flight of some of this prototype instrumentation led to new research directions and showed important new ways to analyze ground-based data (specifically, "destretching" of ground-based images to compensate for large-scale seeing distortions, and three-dimensional Fourier filtering of image sequences to remove the influence of the five-minute oscillation and reveal the true convective flow fields).

It is important to note that the OSL program, while now deferred, has demonstrated very well that it is possible to produce outstanding science as part of the preparations for an ultimate space mission. The MSV-0 program is designed with a near-term scientific return as its central goal, but its activities will also contribute very tangibly to the definition of an optimum MSV-1 space mission. The OSL history is a "proof of concept" that such a science-focussed development pays off in both science return and mission definition. High-resolution solar research is an ongoing process; MSV-0 will build from the very solid foundations established by previous work under the OSL and related scientific programs.

We review here a few important recent results from this previous ground-based high resolution research. They provide a flavor of the significant scientific possibilities that lie immediately ahead under the MSV-0 program.

While seeing conditions on the ground rarely permit taking full advantage of existing telescope apertures, the 60 to 80 cm-class telescopes at Sacramento Peak in New Mexico, Big Bear in California, and at La Palma and Tenerife in the Canary Islands occasionally achieve 0.2 to 0.5 arc-second seeing. Large-format CCD detectors, real-time frame selection, and ingenious analysis algorithms have produced brief glimpses of the small-scale processes that drive solar magnetic fields and granulation. Recent accomplishments include:

a) Observations have clearly revealed a structure and evolution of the granulation pattern which agrees remarkably well with theoretical simulations. Both data and numerical calculations indicate that convection is far more complex than suggested by simple mixing-length theory.

b) While the magnetic field fills only a few percent of the solar surface, observations now show that the field dramatically changes the convection over the entire region in which the fields are found. When the mean magnetic field is greater than 50 to 100 gauss, the granulation pattern changes (Figure 1), as does the amplitude of motions of photospheric gases. There is greater heating in the overlying atmosphere, so that these regions become bright at radio, UV, and X-ray wavelengths, causing significant changes in global solar outputs. Thus we are for the first time able to analyze in detail the magnetic roots from which coronal heating springs.

c) Recent observations indicate that individual magnetic flux tubes are smaller than 0.25 arc-seconds, and also that tiny (normally unresolved) dark sunspot-like structures occur in magnetic regions. Such data, along with the above-mentioned modification of the convective pattern itself, may have significant implications for quantitative understanding of the Sun's overall luminosity variation.

d) Observations of the geometry of the magnetic and flow fields in sunspots have demonstrated that the magnetic field in the spot penumbra is "fluted" on the sub-arc-second scale. This discovery has stimulated a renewed effort in theoretical modeling of sunspots, and a better understanding of the puzzling flows into sunspots.

e) The umbra and penumbra of spots have been observed to have very fine structures and to support a variety of wave phenomena. In highly active sunspots, twists and shears occur on very small scales, and flares often appear rooted at points of highest

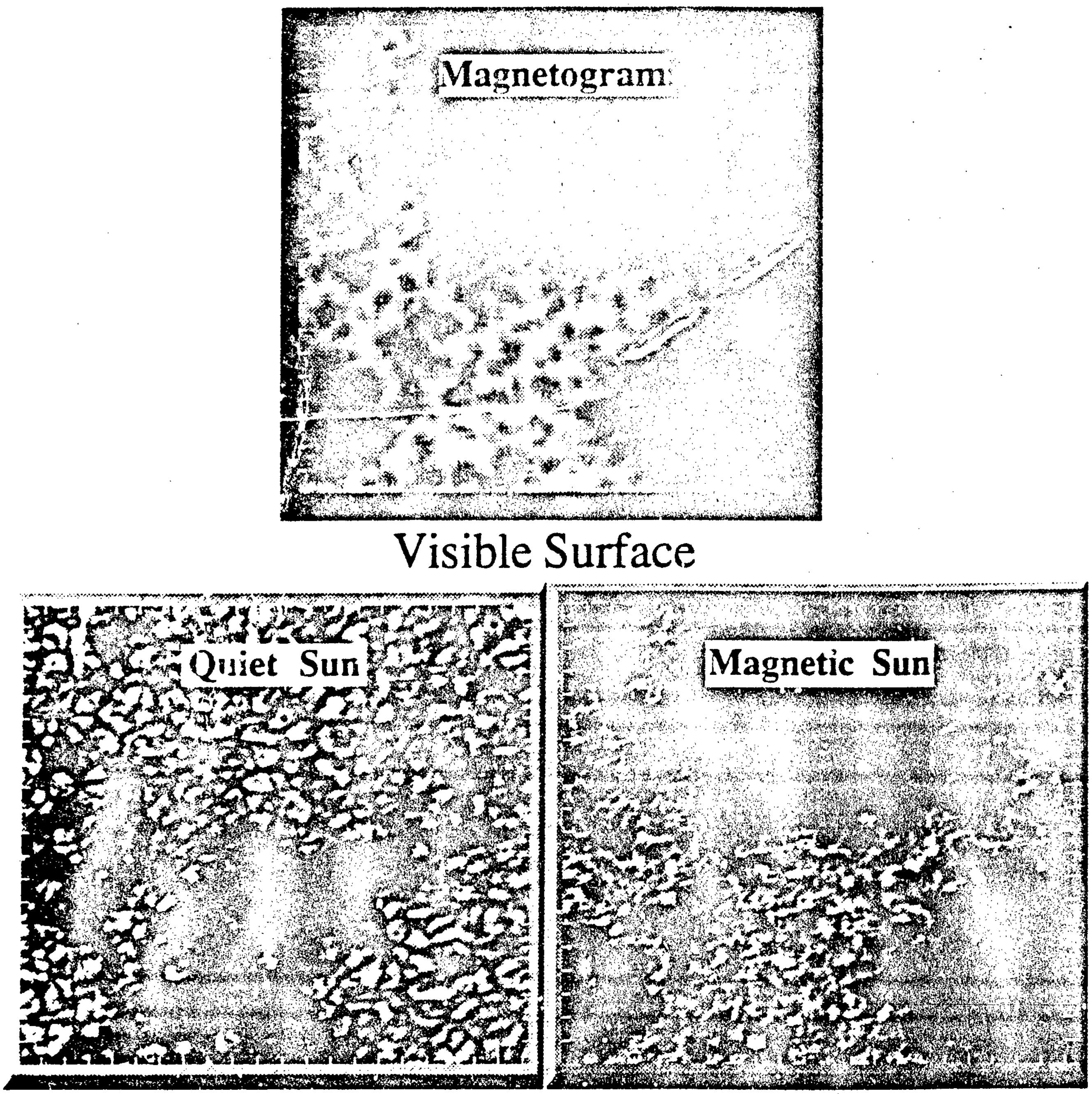

Figure 1. TOP: Magnetogram of 14000 km square on sun (tick marks every 1 arcsec, or 700 km). White regions denote substantial field (> 150 Gauss). BOTTOM: Emission intensity at the photospheric surface (seen in the spectral continuum at 6303.2 Angstroms), shown separately for the non-magnetic (left) and magnetic (right) regions of the area shown in the magnetogram. The left image shows pronounced "granulation" due to fully-developed convection in the non-magnetic regions. The right image shows that convection cells are smaller and deformed in magnetic areas. Courtesy of Lockheed Palo Alto Research Laboratories.

shear, suggesting current driven instabilities. Such data could provide evidence for magnetic storage presaging a flare.

f) High-resolution ground-based data are beginning to reveal the emergence and distribution of magnetic field elements that can combine to produce large-scale effects, such as changes in the overall solar field that governs the magnetic structure in the solar wind throughout the solar system. The field reversal every 11 years, along with the presence of magnetic fields all over the surface, may be due to local magnetic field generation or the disintegration of sunspots and redistribution the spot fields. The reversal of polar fields can be observed directly, and compared to cosmic-ray data.

2.1.3 Proposed Ground-Based Research Activities under MSV-0

Under MSV-0, high-resolution observations such as those described in the last section will continue, building on the earlier results. MSV-0 will take advantage of improved CCD detectors, computer processing, and adaptive optics when available. Exploiting newly-opened regimes of the spectrum and making longer-duration high-resolution observations will be additional observational goals enabled under MSV-0. Some scientific goals include:

a) Transport of magnetic fields on the solar surface is not yet thoroughly understood. The field lines appear to go deep, yet the fields float as if decoupled from the sub-surface layers. New observing and analysis techniques will permit evaluation of the interaction of granulation with magnetic fields to understand this process better.

b) Using adaptive optics it may become possible occasionally to measure the actual Zeeman splitting in the sub-telescopic magnetic elements-thus pinning down the actual magnetic field strength, and allowing detailed calculation of the MHD stresses occurring in the photosphere.

c) Spicules are narrow jet-like structures in the chromosphere and transition zone. While energetically significant and perhaps fundamental to the energy balance of the middle atmosphere of the Sun, they remain poorly understood because of the high-resolution required. With MSV-0, possibly augmented by adaptive optics, we hope to obtain better data on spicules and their relation to the underlying magnetic fields and to impulsive coronal heating.

d) A better understanding of solar flares, the most spectacular products of solar variability, will be an important element of ground-based MSV-0 research. Flares are important both as an extreme example of solar magnetic activity, and because of their practical consequences-for example geomagnetic storms, power grid disruptions, radar and communications outages, satellite orbit changes and electronics systems failures, and atmospheric density, ionization, and temperature variations. The events leading toward a flare start with the concentration of tiny individual threads of magnetic flux into larger magnetic clumps (pores, spots), then into complex active regions with highly twisted and stressed fields, leading finally to violent releases of electromagnetic and particle radiation, and heating of all layers of the solar atmosphere. Almost none of these physical processes have been satisfactorily explained. However, real progress should come from MSV-0 ground-based observations made in coordination with MSV-0 UV and X-ray campaigns, as well as spacecraft such as Yohkoh and SOHO.

e) Because a near continuum of "microflares" has been suggested as a source of the coronal heating, a luminosity function for optical microflares will be established and compared with X-ray and VLA maps, to test this important suggestion.

f) The simultaneous appearance of great active regions and extended periods of good seeing are rare, but will occur occasionally during MSV-0. Observations of pre-flare and post-flare conditions with sub-arc-second image quality should reveal magnetic changes that must occur during flares, but which have almost never been seen.

2.1.4 The Role of Technical Development

Innovative instrument development will be an important part of the ground-based component of MSV-0, for it will help to: (a) push closer to the spatial resolution barrier, (b) increase spectral coverage of solar magnetic variability and, (c) improve observing efficiency and reduce cost. We illustrate these in turn below:

a) An example of pushing the resolution barrier is provided by the recent successful application at Sacramento Peak (after a decade of effort) of adaptive optics to solar observations. Development of this technology will provide limited, but extremely important, snapshots of some of the critical aspects of magnetic and convective physics. (It should be noted that while adaptive optics promises very important high-resolution data on small pieces of the Sun for short periods of time, it can neither replace the steady, distortion-free, large-scale, precise images obtainable from space or balloon altitudes nor provide observations of the physics-rich UV and X-ray portion of the solar spectrum that does not penetrate through the atmosphere to Earth-bound telescopes.) MSV-0 should take advantage of, and could possibly enhance, adaptive optics developments expected to be funded primarily by other agencies.

b) The importance of extending the spectral range of instrumentation is demonstrated by recent improvements in infrared detector technology, which can be exploited to expand the height regime over which magnetic phenomena are measured while at the same time increasing measurement accuracy. At 1.6 microns, significantly deeper layers of the solar atmosphere are observable than in the visible, and infrared measurements of magnetic fields are also unusually accurate.

c) An example of improving observing efficiency, while reducing cost, is the recent successful solar use of volume holographic filtering to provide very narrow-band spectral isolation in solar imaging, and thus potentially to permit more compact optical instruments. (In this technique, an electro-optically nonlinear crystal is illuminated with laser light, setting up a pattern of refractive index inhomogeneities which, after suitable treatment, results in a crystal that reflects efficiently at the same wavelength with which it was illuminated.) Such developments could reduce the size and cost of MSV-0 components such as the Solar Balloon Telescope (Section 2.2.2) as well as the future advanced solar mission (MSV-1) itself.

These three examples are meant only to illustrate the potential of instrument development activities; actual MSV-0 programs would be undertaken only after a competitive selection process.

2.1.5 Operations, Data Management, and Data Distribution

In addition to obtaining new scientific results, the ground-based effort of MSV-0 will include development of operational techniques vital for the flight components of MSV-0 and eventually MSV-1. These include:

a) Real-time handling of solar data rates ($\geq$ 20 Mb/s) far greater than any previously encountered.

b) Compressing, analyzing, and distributing these data.

c) Providing quick-look capabilities.

d) Efficient cleaning, calibrating, filtering and co-alignment of digital images.

e) Planning and conducting simultaneous observations with balloon and rocket flights, and with other ground-based facilities, and subsequent coordinated data analysis.

2.1.6 Interactions within the Solar Community

Also included as an essential part of the ground-based MSV-0 program will be financial and technical support to provide a General Investigator program; namely, observing opportunities both for the general solar community and for the training of graduate students. This will make the latest state-of-the-art instrumentation more easily available to university-based researchers, and allow young scientists to pursue solar physics. The ground-based portion of MSV-0 may involve international as well as national facilities; some of the OSL prototype instrumentation is German built, and part of the observations could be made at foreign sites such as the Canary Islands.

2.1.7 Programmatics

These ground-based efforts will extend over the 5-year life of the MSV-0 program. A suggested budget is $8M, divided into: (a) $4M for operation of existing instruments (for example, but not limited to, those already developed by the OSL PI groups) at several ground-based observatories; (b) $2M to support a general investigator program for community use of such instruments; and (c) $2M for the development of new instrumentation.

2.2 *THE MSV-0 BALLOON PROGRAM*

2.2.1 Overall Goals of the Balloon Program

The MSV-0 Balloon Program will perform discovery-class scientific research by breaking the "resolution barrier" in optical solar physics. It will begin to attack some of the fundamental problems of the MSV program by observing the photosphere and chromosphere with resolution better than 200 km. These observations will be free of atmospheric seeing for extended periods (hours to days) over a field-of-view large enough to study an entire active region and its surroundings. Such study will help in determining the energy budget of active regions as a whole, leading to better understanding of the role that magnetic fields play in controlling the Sun's global energy output. Together with simultaneous, coordinated rocket flights of UV and X-ray instruments, the first high resolution observations of the three-dimensional structure of the solar atmosphere will be obtained. Thus, a few-minute preview of MSV-1 observations will be obtained and placed in the context of measurements of the photospheric magnetic and velocity fields for many hours or days before and after the rocket flights.

The Balloon Program will be incremental, starting with flights of a small telescope and progressing to a meter-class Solar Balloon Telescope (Figure 2), which will obtain the highest resolution solar observations ever made. It will serve MSV-0 in several ways: in collecting previews of the types of data which MSV-1 will produce; in making a major scientific advance in understanding the photosphere, thereby sharpening immensely the scientific focus of the mission as a whole; in generating very large data-sets of images and spectra for the entire solar community to study; and as a technology test-bed, testing new instrumentation that could be applicable for later space flight.

The Balloon Program will obtain observations with uniform high resolution over large areas and long times impossible to achieve from the ground. This will provide a new view of solar magnetic fields, surface convection, and their interaction. Thus, the Balloon Program will glimpse the full power of the observations to come from the MSV-1. For example, the high resolution over entire active regions will allow the stored magnetic energy content of an active region to be tracked with enough sensitivity to measure its depletion during a medium-sized flare. These measurements will test the fundamental idea that a flare draws its energy from magnetic energy stored above the photosphere. The confirmation, or denial, of this idea is critical to our understanding of flares, and hence is of great importance to understanding a broad range of related products of the Sun's magneto-convection, including coronal mass ejections, coronal heating, and generation of the solar wind.

2.2.2 Major Components of the Balloon Program

The first component to be developed will be a solar "ballooncraft," a gondola with systems for solar fine-pointing, data handling, telemetry, power, etc. This will be used first for precursor flights of a small telescope, for example an existing instrument from Spacelab 2. The precursor instrument should have a minimum aperture of 30 cm, a filter vector magnetograph focal plane instrument, and active image motion compensation. The goals of the precursor flights (nominally two flights) will be to collect a first seeing-free data set in coordination with rocket flights, to verify the fine pointing, thermal environment and other features of the ballooncraft, and perhaps to assess the tether mode for more frequent observations with reduced atmospheric seeing. These flights would take place in the United States and would be limited to one or two days, to reduce the cost, complexity, and risk of the operations.

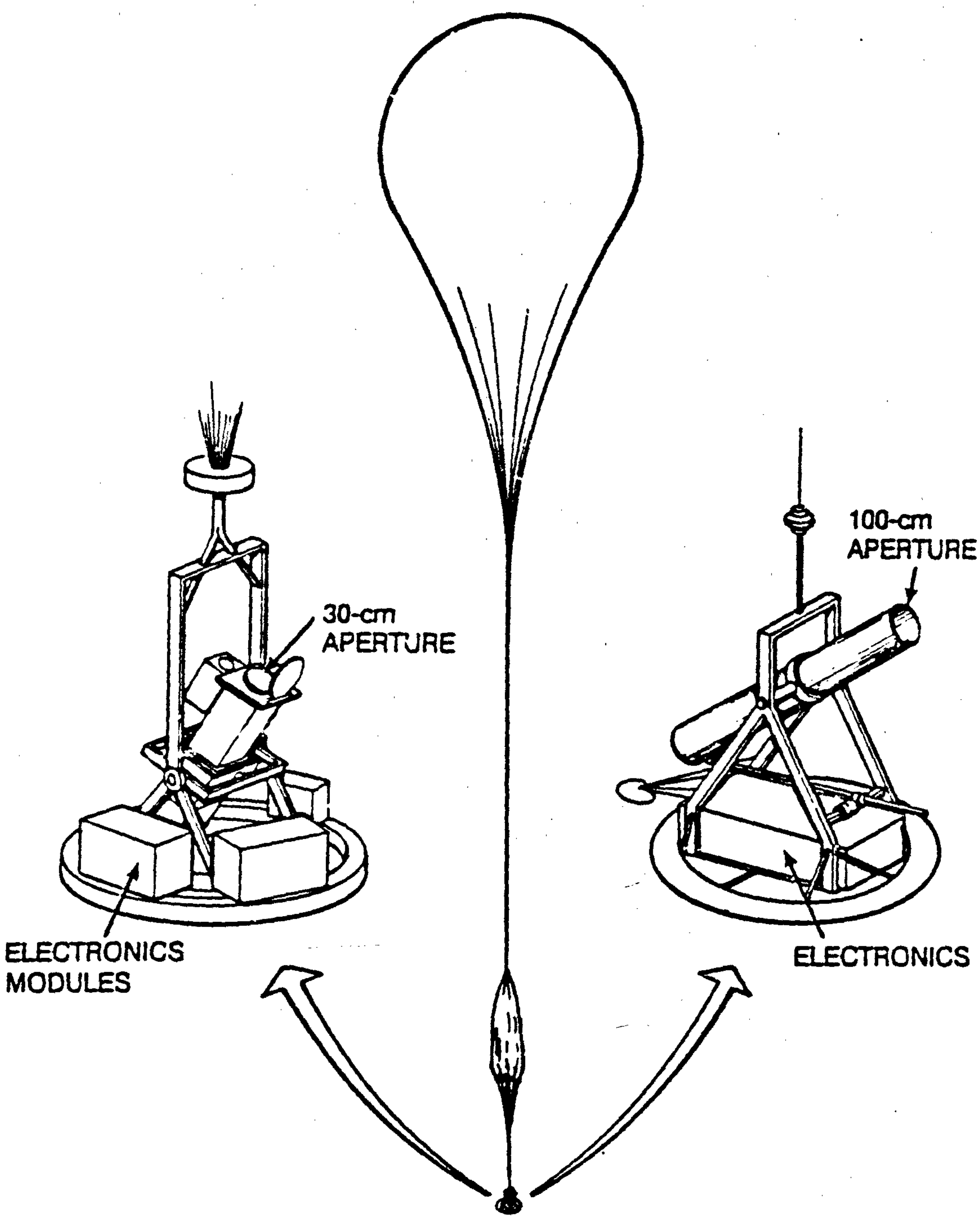

Figure 2. Schematic of the balloon experiments showing both the 30-cm and the 100-cm-diameter telescope payloads. Payloads and balloon not shown to scale.

The centerpiece of the Balloon Program will be a meter-class observatory, the Solar Balloon Telescope (SBT). This will be a visible (and near UV and IR) telescope which can be flown on the same ballooncraft with a variety of focal plane instruments. The instruments would include a filter vector magnetograph, a high-resolution echelle spectrograph (perhaps contributed by an international partner), and new instruments which might be developed under the MSV-0 program (see for example the discussion in Section 2.1.4). The best location and duration of the flights would be chosen based on the precursor flights and ballooning experience to date in New Mexico, Antarctica, and Australia. Consideration would also be given to the use of a tethered balloon to increase flight frequency and duration; as already noted the feasibility of this approach could be assessed during the Precursor phase.

It would be expected that the SBT would become a long-lived facility, with many flights even beyond the end of the MSV-0 program, perhaps even extending to the time of flight of the MSV-1 itself. If tethered operation proves to be successful, many flights could be conducted. This would very substantially increase the science/cost effectiveness of the programs.

Each flight, including the precursors, would be planned from the start with coordinated observations from ground-based observatories, rockets, and the SOHO instruments. The complete set of data from the campaign, including hours to days of superb image data, would be coaligned, merged and studied together by the team of PI's, Co-I's and GI's according to the data policy of the MSV program. The data management effort would include software to compare the different data-types and relevant simulation data, drawing on the base of experience and software from the ground-based observing segment of MSV-0.

2.2.3 Programmatics

The straw-man budget and schedule for the Balloon Program is as follows:

Ballooncraft Development	$1.2M, largely in FY 94–96
Precursor Flights (2)	$4M, FY 95–7
SBT Development and Flights (3)	$10M, FY 94–98
Scientific Investigations	$4M, FY 94–98.

2.3 *THE UV, XUV, AND X-RAY COMPONENT OF MSV-0*

As already noted, it is essential to measure the solar atmospheric response to photospheric magnetic forcings, in order to calibrate the actual variability that occurs as a result of those forcings. This variability takes the form of spatial and temporal emission variations at UV, XUV, and X-ray wavelengths, together with dynamic effects such as the solar wind and its variations, mass ejecta, and particle acceleration. The coronal structures and their variations must be studied at high angular resolution (arc-second or better) to isolate discrete features and events, and must be relatable in time and space to the underlying photospheric phenomena. The necessary data can be obtained under a program of rocket flights incorporating existing and newly developed instrumentation, supported or augmented by the MSV-0 program, where the rocket observations are carried out in coordination with visible observations of the photosphere.

2.3.1 Scientific Rationale

The Sun's UV and X-ray radiation shows large changes over a solar cycle-a factor of two at Lyman alpha increasing to approximately a factor of ten in the X-ray region. Because of the short duration of our record of the UV spectrum, we have little information on the long-term climatological consequences of changes in this part of the solar spectrum. We do, however, know that short wavelength variability causes large variations in the chemistry and thermal structure of the upper atmosphere that may influence the dynamics of the upper troposphere. Effects of the variability of the Sun's UV and X-ray spectrum are now included together with joule heating due to geomagnetic activity in numerical models that extend to the tropospheric-stratospheric boundary. Measurement of the total solar radiation field at short wavelengths provides an essential boundary condition for these models as they are extended into the lower atmosphere. It is very important to understand the origins of variations in the Sun's UV and X-ray radiation, which requires study of how time-varying radiation from coronal features relates to underlying magnetic forcing.

The detailed understanding of solar UV/X-ray magnetic variability also has important implications for wider astrophysical issues, whether it be the study of coronal emission from other stars seen by AXAF or other satellites, the study of X-ray transients from stars (flares) or other more complex magnetized systems such as accretion disks, etc. MSV-0 will contribute, directly or indirectly, to many areas of high-energy astrophysics because of the detailed microscopic investigations of mechanisms it will permit.

The solar UV and X-ray variations originate in the outer layers of the solar atmosphere, especially the transition region and corona, in regions permeated by magnetic field. Thus the solar variability is related to physical processes originating in field-plasma interactions. In fact the heating of the corona itself is one manifestation of the process leading to UV/X-ray variability.

Particularly important in understanding solar UV/X-ray variability is the connection of the magnetic field to underlying photospheric and chromospheric structures. With the development of X-ray imaging capabilities at the arc-second level, it is now becoming possible to make detailed comparison of the geometry and spatial location of coronal features relative to their underlying photospheric drivers. For example, Figure 3 shows a rocket image with a white light contribution through the same optical system; fine coronal emission loops are seen to descend to magnetic fibrils in the penumbra surrounding a large spot-not to the dark center of the spot itself. Such data should yield important clues to the heating of coronal loop structures and their consequent X-ray emission.

The low density regime of the corona and transition region is significant because it allows magnetic instabilities to develop, resulting in transient energy release and mass motions. The energy release, at coronal altitudes, may be relatively slowly varying, as in the case of active regions (which collectively give rise to variations on the time scale of the solar cycle) or, at the other extreme, may be rapidly varying and intense on short time scales (as in flares). In either case the heating, in turn, influences or fundamentally alters structures in the lower atmosphere via back conduction, irradiation, or particle penetration; hence the solar photosphere and its overlying atmosphere act as a fully coupled system.

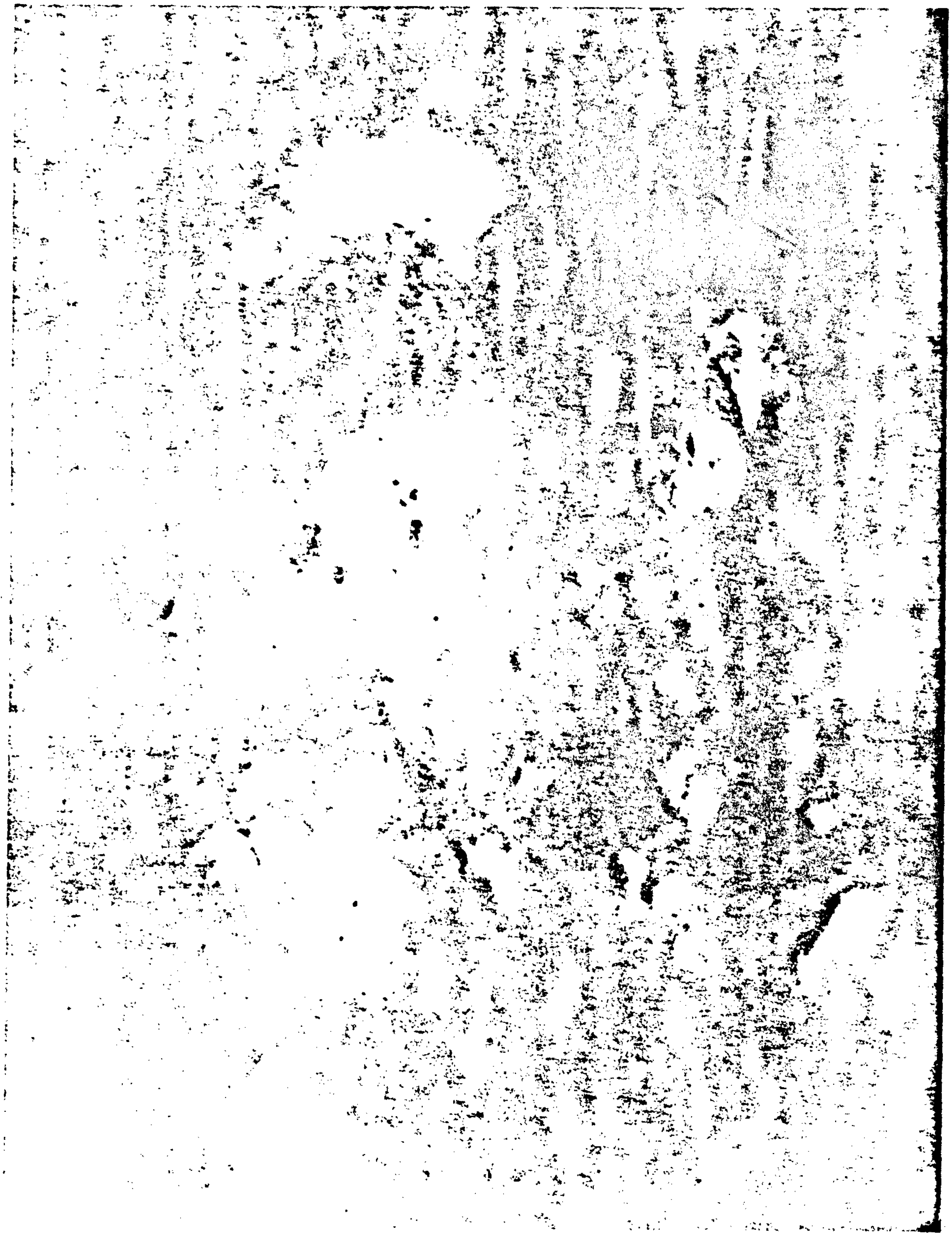

Figure 3. Normal Incidence X-ray Telescope (NIXT) image, which has a few percent visible light component. Because of the background visible image, the location of the fine X-ray loops with respect to surface features can be clearly seen. Image courtesy L. Golub, Center for Astrophysics, and G. Spiller, IBM Research Laboratory.

Thus a fundamental requirement for understanding solar UV/X-ray variability is high resolution observations of the structure, dynamics, and energy balance of the transition region and corona in regions of the evolving magnetic field. Of course temporal changes in solar structure (with the exception of very short term changes) cannot be measured with rocket instrumentation; instead, the rocket observations will obtain snapshots of the coronal and transition region conditions and processes in the context of a sequence of observations of time-varying photospheric magnetic and velocity fields, obtained from the ground or balloons at visible wavelengths. Additionally, continuous observations acquired by Yohkoh and SOHO, although at lower spatial resolution, could be used to establish continuity, at the same time that they provide a global context.

Because the magnetic field is highly filamented and variable on small spatial scales, high spatial resolution is an absolute necessity. Previous observations of these structures, obtained by satellites and rockets, show detail down to the limit of instrumental resolution, at best of order 1-2 arc-second. However, density measurements from spectral analysis indicate filling factors which imply spatial scales on the order of 100 km. Thus resolution of approximately 0.1 arc-seconds may ultimately be required to completely resolve the field structure, although much can be done initially with resolution of about 1 arc-second.

2.3.2 MSV-0 Rocket Program Elements

A plan for obtaining UV/X-ray observations in collaboration with simultaneous observations at visible wavelengths can be achieved by rocket flights in several phases of increasing sophistication and spatial resolution, as given below. The degree of progress achieved will be dictated by available resources under the MSV-0 program and the existing SR&T and suborbital programs which already support some rocket studies of this type.

Phase I. Beginning in 1992 (before MSV-0) and funded under existing SR&T program: Near-simultaneous rocket flights (separated by 30 minutes) of two or three experiments (one experiment per rocket) with coordinated Yohkoh X-ray images: UV spectra, spectroheliograms, XUV images. These would be obtained with existing instrumentation, providing 0.5-1.0 arc-seconds resolution. After 1993: Same experiments, but now flown on rockets launched simultaneously. There would be coordination with SOHO/EIT observations, providing broader spectral coverage and continuity at XUV wavelengths, later in the program.

Phase II. Continuation of Phase I activities, but flown on a single larger rocket with a multiple payload capability. Simultaneously, however, larger UV/XUV telescopes and advanced instrument payloads would be developed under MSV-0 funding. The larger rocket would accommodate telescopes with apertures providing 0.1 arc-seconds resolution. NASA would be required to develop a suitable pointing system for this phase.

An additional program in support of the above includes development of detector systems suitable for short wavelengths. This is especially important for very high-resolution imaging, where detectors with very small pixels are required. It should be noted that rocket flights early in the program could co-observe with Yohkoh, and later ones with SOHO.

2.3.3. Programmatics

MSV-0 will provide funds for high-resolution UV/X-ray solar research that goes beyond existing rocket programs. First, MSV will permit a needed expansion of present capabilities by funding one new group for research with Black Brant rockets ($350K for 3 years = $1.05M). (The existing solar branch sub-orbital program will continue to fund two other rocket groups in support of this area of science, as well as data analysis for all three.) Second, MSV-0 will fund the development of the single larger rocket with multiple payload capability, at a funding level of $1.5M. Finally, MSV-0 will fund the development of a large aperture UV/X-ray rocket payload capable of 0.1 arc-second resolution, at an estimated cost of $3M. At the same time, $1.05M will be invested in development of advanced UV/X-ray detector systems.

2.4 *THEORY AND MODELING*

2.4.1 Introduction

MSV-0 requires a strong and immediate theory program to accompany the hardware and observation efforts. Theory and modeling of solar processes have progressed remarkably in the past few years, to the point where, for the first time, we can make real physical sense out of the complex phenomena being observed. Without theoretical understanding the observations reveal fascinating, but uninterpretable, details about the key processes that cause the Sun's UV, X-ray, and total luminous outputs to vary. At present, we have only order-of-magnitude theoretical models for these processes-whose understanding is a central goal of the MSV program. It is clear, therefore, that a great deal of progress on theory must be made before we will have achieved the science goals of the MSV-0.

In addition to its key role in providing the framework for understanding solar magnetic processes, theory also plays an important part in specifying the hardware and observational programs that will produce the needed data. The experimental program of MSV-0 has been developed to answer well-defined questions such as the dependence of surface radiative flux on magnetic field, and the connectivity of coronal loops to the photosphere. But theory is needed to specify the critical parameters to be observed and the measurement precision required, so that first the instruments and later the observing programs can be most intelligently designed. Fortunately, considerable progress has already been made in developing theoretical models and numerical tools that are directly applicable to the design and use of MSV-0 instruments. Excellent data from ground-based and rocket experiments are available now, and improved observational projects will be begun immediately as part of the MSV-0 program. Hence, there would be an immediate payoff by initiating the theory component early, so as to contribute optimally to program development.

Finally, theory is needed as part of the data analysis process, in order to extract the required physical parameters from the raw data. For example, the optical observations, no matter how accurate, will not measure the properties of the solar convection below the photosphere. Theoretical models of convection in a compressible magnetofluid and numerical inversion techniques will be needed to determine the subphotospheric velocity and magnetic fields from the surface observations. Similarly, UV and X-ray observations alone are not sufficient to determine the coronal magnetic field. Theoretical MHD models will be needed to constrain the coronal field from observations of the photospheric field and the coronal plasma. Fortunately, there has been enormous recent progress in relevant numerical modeling capabilities, so that there is now the possibility of a true match between theoretically computed and experimentally observed quantities. The situation in photospheric and coronal physics is similar to that in helioseismology, where during the past decade there has been tremendous progress due to an almost perfect match between theory and experiment. The time is ripe for similar rapid progress in the area of solar convection, magnetism, and associated variability.

2.4.2 Key Theoretical Problem Areas

We list here some key problem areas that are central to obtaining the desired return from the MSV program:

- Predictions of observable properties of solar convection.

  Numerical simulations of solar convection have made great progress in recent years. This type of theoretical work is very exciting and extremely important to the MSV program. It promises to explain such fundamental issues as the formation of flux concentrations in the photosphere, and the origin of the solar luminosity variations. Several groups have now developed three-dimensional compressible convection codes. These include much of the important physics such as optically thick radiation, and have spatial resolution matching present ground-based data. Hence, we can use simulations to calculate observables for direct comparison with, and interpretation of, optical observations. Numerically calculated convective patterns, after smearing to mimic the effects of atmospheric seeing, look remarkably similar to actual granulation observations. The numerical simulations do more, however, than replicate observed patterns: by allowing a theoretical glimpse into the behavior of convection in deeper layers, they are producing a new understanding of the physics of convection. For example, the numerical calculations shown in Figure 4 demonstrate that convective "plumes" may descend at least four pressure scale heights, quite contrary to "mixing length" of convection. Such results may have important implications for the transport of magnetic fields between the surface and deeper layers; this may prove important for theories of the solar magnetic dynamo.

  Numerical modeling is necessary not only for interpreting present data, but also for guiding future observations. For example, the presence of supersonic convection, first predicted by the numerical simulations has recently been confirmed observationally. This synergism must be continued in the MSV-0 program. Further development of the theoretical models is required. In particular, effects such as a self-consistent magnetic field remain to be included and the numerical resolution must be increased to the scale of the future balloon-borne MSV-0 observations.

- Determination of observational signatures of coronal heating models.

  During the past decade there has been a great deal of theoretical and observational effort devoted to the issue of coronal heating. The critical question is: how is magnetic energy transferred from the photosphere to the corona, and how is it dissipated? This is the underlying physics for understanding the origin of all stellar coronae. Several models have been developed for heating either by DC currents or

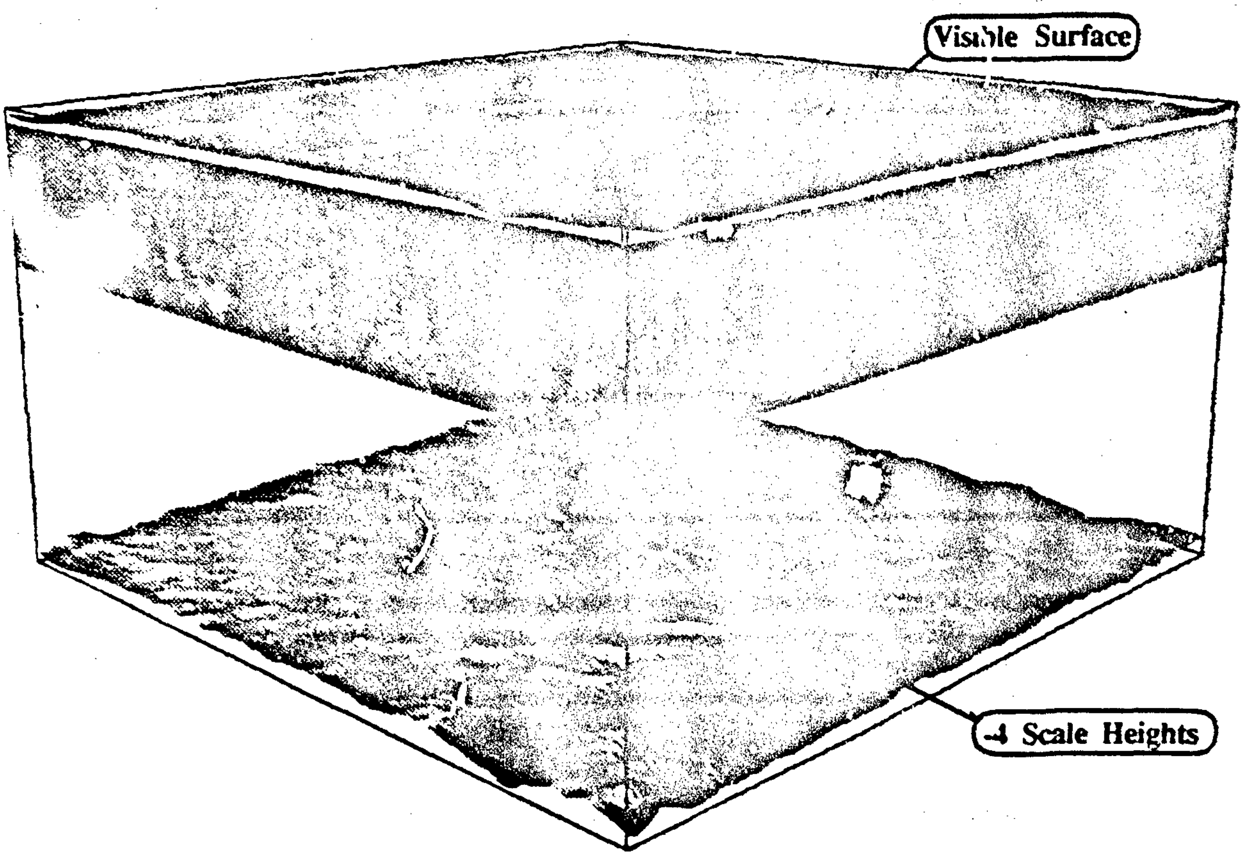

Figure 4. An oblique view of a simulation of solar convection. Here the vertical velocity within the simulation is displayed on a various planes with a gray scale. Regions of downflow are black while regions of upflow are white. The physical scale is the same in the horizontal and vertical directions, but the vertical scale spans four pressure scale heights. The lower surface has been displaced downward for visibility. Strong downflows extend from the top to the bottom of the model. However their topology changes from a connected network at the surface to more isolated plumes as they descend.

by Alfvèn waves. These models appear consistent with the present low-resolution observations, i.e. total power rates and average photospheric velocities and magnetic field strengths. Hence, it is not possible to determine the correct mechanism for coronal formation with the present data and the present models.

Theoretical calculations are now needed for the different mechanisms, which will yield detailed predictions of direct observables such as morphology and spectra. These predictions can then be compared with the high resolution coordinated observations to be obtained with the MSV-0 multi-wavelength program. A key goal of the theoretical effort will be to determine the coronal magnetic field and electric current structure from the observations. Within the last two years, three-dimensional numerical codes have been developed for calculating both magnetostatic and dynamic models of the coronal field. So far the simulations have been run at relatively low resolution, so that the work has concentrated more on understanding the basic physical processes rather than comparison with actual data. However, both the numerical tools and the computational resources are now available so that simulations with sufficient resolution to predict MSV-0 observables can be attempted. Again the theory and the experiment hardware must be developed jointly so that there be an effective synergism, and definitive tests of the heating mechanisms are obtained.

- Determination of subphotospheric magnetic fields.

High resolution optical observations from MSV-0 will provide a wealth of helioseismology data at ultra-high spatial frequencies. It is now known that 50% of the power in acoustic waves (p modes) incident on a magnetic active regions is absorbed. In addition, it has recently been shown that p modes scattered by active regions are phase shifted relative to the incident waves. The absorption coefficients and phase shifts imply that p-mode scattering can be used as a powerful probe of magnetic fields below the photosphere, since the waves propagate to significant depths. Depth dependent information is contained in scattering data from modes that penetrate to different depths in the solar atmosphere. The important theoretical goal will be to derive, from the set of absorption coefficients and phase shifts, the structure of magnetic fields *below* the photosphere.

- Measurement of magnetic energy release in flares.

The equilibrium (nonflaring) configuration of an active region's magnetic field in the chromosphere and corona can differ only slightly from a force-free configuration, because the magnetic pressure greatly exceeds the plasma pressure. This allows, by application of a virial theorem for force-free fields, the total magnetic energy content of an active region to be measured from a vector magnetogram of the field at the photosphere. The accuracy to which the total energy can be evaluated from a real vector magnetogram increases linearly with both the spatial resolution and the magnetic sensitivity of the magnetogram. For this method of measuring an active region's magnetic energy, the expected improvement in energy sensitivity with increase in spatial resolution is shown in Figure 5.

Figure 5 indicates that the improved spatial resolution provided by a balloon-borne vector magnetograph should allow the magnetic energy of an active region to be

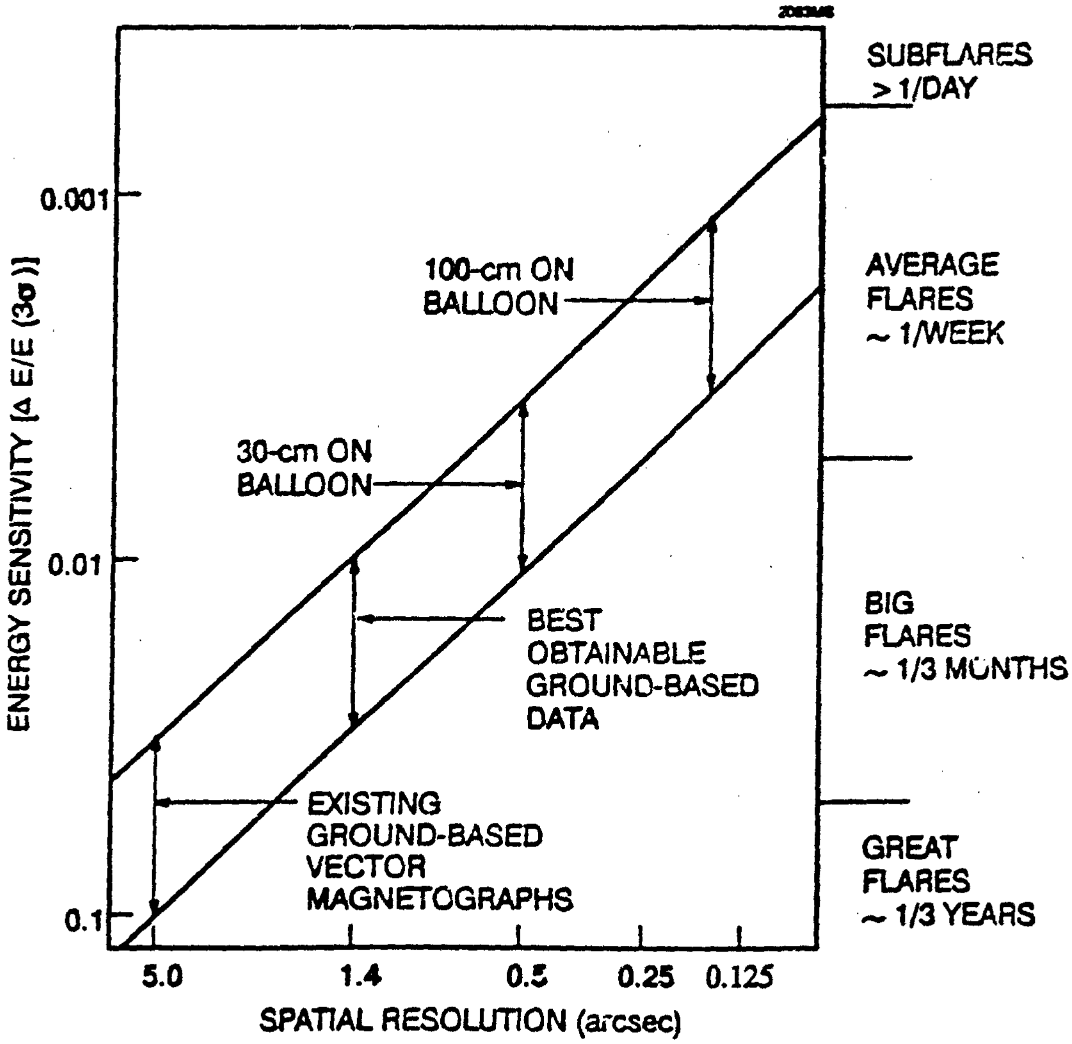

Figure 5. The detectable fractional change in an active region's stored magnetic energy following a flare, as a function of the spatial resolution of vector magnetic field observations of the region.

tracked with enough sensitivity to measure, for the first time, the magnetic energy depletions predicted for typical flares. But how reliable is this graph? The magnetic field at the photospheric depth that present vector magnetographs observe may be far from force-free in those flux elements that are being pushed about by the granulation and other convective flows. How much does this affect the force-free energy integral? Will it be necessary to develop a vector magnetograph that observes in the low chromosphere (in UV or IR) in order to achieve the accuracy shown in Figure 5? These are questions that need to be investigated quantitatively with detailed applied theory and modeling of active-region magnetic fields in the photosphere and chromosphere.

- Determination how localized magnetic variability affects global outputs.

  Of particular interest for both solar-terrestrial and astrophysical research is how the processes studied under MSV-0 affect the integrated output of the Sun—both integrated over the visible hemisphere (and hence varying with rotation) and integrated over the entire surface. Theoretical study of how long energy, blocked from escape by surface fields, may be stored in the convection zone, and where and how it is finally reradiated, is fundamental to this question. While there has been encouraging progress in studying this topic, much more remains to be done. As usual, theory will be led by observations-for example by the recent discovery that in stars much younger than the present day Sun (and presumably in the Sun when much younger) the relation between overall luminosity variations and the level of magnetic activity is the opposite of that for the Sun.

2.4.3 Programmatics

Based on the discussion above, we find a need for at least two groups working on large-scale numerical simulations, one group concentrating on the photospheric science and one concentrating on chromospheric and coronal science. In addition, there is a need for two or more smaller-scale efforts to address specific problems such as the last two discussed above. This theory program will require a budget of approximately $600K/year, or approximately $3M over the duration of the program. The funds will be awarded by open competition with the two overriding selection criteria being scientific excellence and importance to the MSV-0 program. Note that this will be to a large extent an "applied theory" program; the goal will be not only to make progress on understanding the fundamental physics of solar variability and to develop that into a global context, but also to deliver specific and necessary inputs to the experimental effort.

3. PROGRAM AND BUDGET

3.1 *PARTICIPATION*

It is envisioned that all funded participation in the MSV program will be in response to a single NASA Research Announcement (NRA). The investigations will be Principal Investigator (PI) ones, wherein each selected PI takes full responsibility for the conduct of the investigation. Proposals from interdisciplinary scientists and scientists not proposing to provide hardware should be included in the solicitation. Contributions to the goals and programs of MSV from scientists with funding from other sources are foreseen and encouraged. The NRA should be open to foreign investigators funded by their own governments. International collaborations, including, where appropriate, those already selected for OSL, should be encouraged. Creation of new permanent positions for solar physics in educational institutions, and involvement of students in research, should be favorably considered in selecting responses to this NRA, in order to meet the need of the discipline for fresh talent to conduct MSV-1 near the turn of the century.

In order to focus and coordinate the MSV effort, distributed as it will be among research groups employing different observational and theoretical techniques, regular workshops should be held (one per year), involving all participants, and resulting in a series of workshop proceedings. (Of course, principal publication of research results would be in standard refereed journals so as to get wide and rapid distribution of information.)

It is important that the selection of MSV participants take maximum advantage of the investment already made in the OSL. While an open and unrestricted NRA is planned in order to encourage innovative and cost-effective new approaches, there is a strong community consensus that existing OSL PI teams should be supported by other NASA channels at least up to the time of initiation of the MSV-0 program, in order that the OSL investment not be lost or diminished. This will optimize the scientific and technical program of the MSV program.

3.2 *ORGANIZATION*

The principal bodies coordinating this enterprise should be an Investigations Working Group (IWG) and a Project Office (PO).

The IWG will consist of the PIs of all selected investigations, additional investigators who would represent key investigations funded from other sources, and (ex officio) the Project Scientists and the Chief of Solar Physics at NASA HQ. It would be consulted on all substantive programmatic issues, including cost and risk trades. The IWG would be responsible for the program meeting its scientific goals. It would report to NASA HQ and coordinate directly with NASA center management and the PO as needed.

The IWG would formulate policy on data distribution and sharing to maximize the scientific return from MSV. A model for such a policy might be that already developed by the OSL Science Working Group, which incorporates a data-sharing agreement, coordinates publication rights, fosters cooperation, assures wide data availability, and promotes sensible commonality of software and data formats.

The PO, based at a NASA center, will provide a Project Manager, Project Scientist, and supporting staff. Its responsibilities are to:

- facilitate the selected investigations
- assist in coordinating the project operations
- provide a systems overview
- provide services such as parts or testing
- administer project safety and budget
- provide advocacy for the project within NASA

The management goals of the program, to which both the IWG and PO contribute in their respective roles, are to:

- optimize the effectiveness of the total program effort
- obtain the maximum science per dollar expended including the funds already invested in the OSL
- reduce the cost and risk of achieving the goals of an eventual MSV-1
- ensure that the latest technology is available for MSV-1
- maintain PI responsibility for the success of the enterprise
- establish and maintain effective communications among the diverse participants
- coordinate and integrate the program elements in order to achieve the focused objectives
- conduct the program within available resources

3.3 *SCHEDULE*

The ground-based component of MSV-0 will continue throughout the program. Specific observing campaigns will be scheduled at times of balloon and rocket flights.

The balloon-based component would commence with the development of the ballooncraft and a 30 cm-class instrument in 1994 leading to a first "precursor" flight in late 1995 and a second flight eight months later. The meter-class telescope would start definition in 1994, leading to a first flight in late 1996 and two follow-on flights at eight month intervals.

The rocket program will begin with augmented Black Brant flights in 1994, 1995, and 1996. Multiple payload flights of UV and X-ray instruments will occur in the last quarters of 1995 and 1996. The development of a larger, 0.1 arc-second UV/X-ray payload will begin in 1995, with two flights in 1997 and one in 1998.

Theoretical efforts will continue at a steady rate throughout the program.

3.4 *COST*

The total funding required to conduct the proposed scientific program is estimated to be $37.6M in FY '92 dollars, spread over 5 years from FY '94 through FY '98 inclusive. The funding profile is shown in Figure 6. While it is envisioned that there would be a separate selection of investigators for MSV-1, it is both desirable and important that the program transition gracefully to the MSV-1 era, and thus there would be a one-year overlap with the start of MSV-1 if that start occurs as presently baselined.

Cost elements are listed below and laid out in time in the following table.

- The Ground-based Component of MSV-0 ($8 M)
  - Momentum in high resolution ground-based solar research ($4 M)
  - General Investigator Program ground-based research ($2 M)
  - Instrument technical development (algorithms, detectors, optical & UV/IR components, processes) ($2 M)

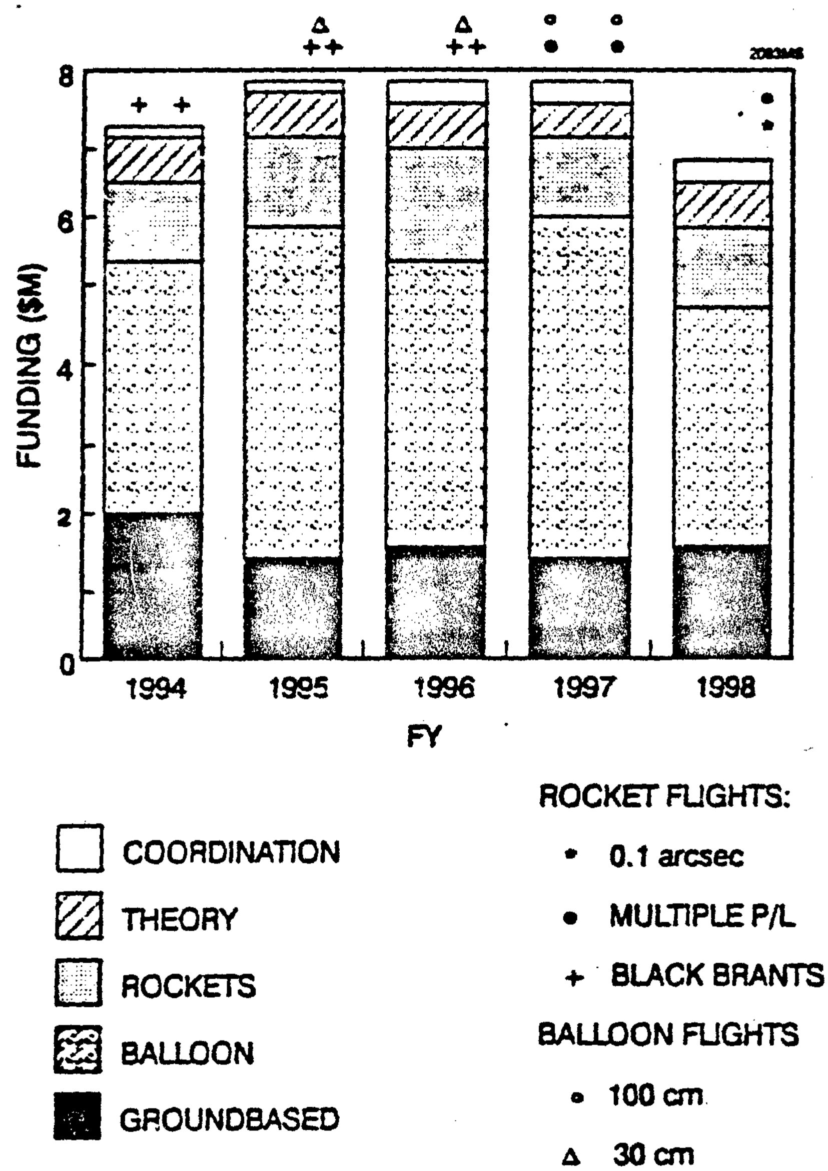

Figure 6. Funding profile for MSV-0. Indicated on the figure are the times of the rocket and balloon flights.

- The MSV-0 Balloon Program ($19.2 M)
  - Ballooncraft (solar "facility") development ($1.2 M)
  - Precursor (0.5 arc-second magnetic fields), 2 flights ($4M)
  - Observatory (meter-class) development and 3 flights ($10 M)
  - Scientific investigations ($4 M)

- The UV, XUV, and X-ray Component of MSV-0 ($6.6 M)
  - Additional Black Brant payload, 6 flights with precursor balloon ($1.05 M)
  - UV/XUV/X-ray detector development ($1.05M)
  - Two ganged, multiple payload flights ($1.5 M)
  - Sub-arc-second payload development and flight ($3 M)

- Theory and Modeling ($3 M)
  - Proposed program with two large, two small groups ($3 M)

- Coordination ($0.8M)
  - IWG meetings (2 per year) ($0.5 M)
  - Science conferences (3 in 5 years) ($0.3 M)

	FY 94	FY 95	FY 96	FY 97	FY 98	Subtotal
Groundbased						8.00
Observations	0.80	0.80	0.80	0.80	0.80	4.00
GI Programs	0.20	0.20	0.40	0.50	0.70	2.00
Technical Developments	0.90	0.50	0.40	0.15	0.05	2.00
Balloon						19.20
Craft	0.40	0.20	0.30	0.20	0.10	1.20
Precursor	1.20	1.50	0.50	0.80		4.00
SBT 0.1 arc-seconds	1.60	2.20	2.20	2.30	1.70	10.00
Scientific Investigation	0.20	0.30	0.80	1.30	1.40	4.00
Rockets						6.60
Black Brant	0.35	0.35	0.35			1.05
UV/X-ray Detector Development	0.35	0.35	0.35			1.05
Multiple-Payload	0.30	0.40	0.40	0.30	0.10	1.50
.1 arc-seconds	0.30	0.40	0.60	0.80	0.90	3.00
Theory						3.00
GI Program	0.60	0.60	0.60	0.60	0.60	
Coordination						0.80
IWG Meetings	0.10	0.10	0.10	0.10	0.10	0.50
Scientific Conference	0.07	0.01	0.07	0.07	0.08	0.30
Total	7.37	7.91	7.87	7.92	6.53	37.60

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